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Review

Solutions for real values in Minkowski four-dimensional space may link macro- and micro-quantum processes in the brain

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ABSTRACT

To test the application of Minkowski space-time (hyperspace) to brain function, the time-dependent inflection values required for a non-negative solution of $\sqrt{(x^2+y^2+z^2-c^2t^2)}$ was solved for four functional cerebral spaces. The single electron orbit time for the cell membrane, the "neuroquantal unit" of $\sim 10^{-20}$ J for the cell width, the frequency of the universal hydrogen emission (precession) line for cerebral length, and one-half of Planck's constant (the spin of particles constituting matter) for the thickness of the charges associated with the cell membrane potential were the primary solutions. These values may reflect the critical times (or frequencies) when operations shift from imaginary to real within the 4D human brain and could define the thresholds optimal for the transition between energy and matter.

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1. Introduction

A human brain is a mass that occupies space for a discrete duration of time. Although the latter is reflected in the micro- and macro-structural changes associated with ontogeny, the brain as a space-time phenomenon has usually been considered a metaphor rather than an actual metric. Recently the question of whether or not Minkowski space has a veridical equivalent to its theoretical existence has been considered in physics (Petkov, 2007). In the present paper the relevance of this particular formulation of the space-time continuum to the fundamental properties of the human brain are considered.

The concept of the human brain existing as a space-time phenomenon has been developed by imaginative writers for at least two centuries. Recently psychologists and neuroscientists have employed terms such as "mental time travel" (Lavalle and Persinger, 2010) to approach the subjective temporal dimension within cerebral space. However there are more powers of ten between our brain boundaries and the smallest derivable length ($\sim 10^{-35}$ m) and time ($\sim 10^{-44}$ s) than there are between our brain space and the estimated width ($\sim 10^{26}$ m) and time ($\sim 10^{17}$ s) of the universe. If time and space are components of an aggregate that more optimally describes the properties of matter and energy, then applying this solution to the essential physical dimensions of the brain could expand our understanding of this "great raveled knot".

In its classic form Minkowski space (Reichenbach, 1958) is a four-dimensional expression of Pythagorean geometry expressed as $\sqrt{x^2+y^2+z^2-c^2t^2}$ where x, y, and z refer to the three axes of space, t is time, and c is the velocity of light. Because the square root of a negative number is defined as imaginary, a "real" solution must involve $\sqrt{}>0$, that is, a value greater than 0. The involvement of c determines that t must be a very small value in order to solve for a

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Table 1
Selected universal constants and approximate order of magnitude values in comparison to brain space-time.

Mass of the universe, 10^{52} kg
Planck's mass, 2.2×10^{-8} kg
Mass of 10 μm soma, 10^{-13} kg
Atomic mass unit, 10^{-27} kg
Upper estimated limit to rest mass of a photon, 10^{-52} kg
Smallest derivable length (Plank's), 10^{-35} m
Width of a proton or electron, 10^{-15} m
Bohr radius, 5.2×10^{-11} m
Width of atomic bonds, 10^{-10} m
Plasma cell membrane, 10^{-8} m
Median neuronal soma diameter, 10^{-5} m
Length of human cerebrum 10^{-1} m
Longest duration (age of universe), 10^{17} s
Life of human being, $\sim 2 \times 10^{9}$ s ($\sim$2 Gs)
Cerebral microstates, 10^{-1} s
Duration of action potential, 10^{-3} s
Life time of hydronium atom (H_3O^+), 10^{-12} s
Bohr electron rotation, 6.8×10^{15} Hz ($\sim 10^{-16}$ s)
Shortest derivable time (Planck's), 5.4×10^{-44} s

minimally positive value. When quantitative solutions are obtained to shift the solution from imaginary to real numbers, the values are not only revealing but suggest a more cosmological origin to brain structure and function.

"Cosmological" is defined here as a direct quantitative relationship to physical constants and universal properties of matter and energy. Some selected classical constants and approximate values that define the boundaries of space and time are shown in Table 1. The approach could be considered a variation of the late 19th century physicist Ernst Mach's *principle of imminence of the universe* that assumes the properties of local matter depend upon the presence of the remainder of the universe (Krogdahl, 1962). The primary corollary predicts that the laws governing matter on the large scale should be intimately related to the laws that determine matter within much smaller scales. What is not clear is by what metric these scales are "connected".

Von Euler's formula of $e^{i \cdot \pi} = -1$ related imaginary (i) domains to two constants of our universe: the transcendental real number for the base of the natural (Napierian) logarithmic system: e ($\sim$2.72) and the irrational number for the ratio of circumference to diameter: π ($\sim$3.14). However, "real" vs "imaginary" existence may be more than a mathematical convenience. That imaginary or "virtual" particles (vacuum oscillations) can transform to real or actual particles is a critical assumption of the Casimir effect (Bordag et al., 2001) which can occur as macroscopic manifestations of quantum phenomena. The effect is relevant to neuroscience because it is the interaction between a pair of neutral, parallel conducting planes due to disturbances of the ground state of quantum electrodynamics. The required ratios for surface area-to-plate separation are very similar to the geometric properties of the synapse.

The existence of zero-point oscillations is assumed to reflect the "infinite" energy of free space. Boundaries from changing densities of matter polarize the vacuum of a quantized field. The resulting force acting on the boundary is a consequence of this polarization. The transfer of energy from the external field to the virtual particles transforms them to real ones (Bordag et al., 2001). If the boundary conditions depend upon a particular time, particles are created as well as a force (Newtons). Force distributed over distance is energy, measures in Joules.

The shift in perspective from force to energy has paramount significance for biological systems. A force that may be negligible can be potent when applied as energy. Dropping a 1 g mass from a height of 0.5 m produces a force in the order of milliNewtons (10^{-3} N) on the surface of the palm that is propioceptively barely discernable. The energy associated with that impact (a few microJoules, 10^{-6} J) would be sufficient, if applied at the appropriate frequency, to produce the experience of light in a dark-adapted setting (threshold of about 10^{-17} J) for *every* living person on this planet.

Extremely small energies define the elemental phenomena from which emerge at larger spaces and longer times the major operating correlates of brain function and its experiential properties. The amount of energy associated with the net change of voltage of a single action potential (1.5×10^{-1} V) upon a unit charge (1.6×10^{-19} As) is about 2×10^{-20} J (Persinger, 2010). This is the same order of magnitude as the intermolecular energies between ligands and receptors (Moy et al., 1994). It is also the energy between the velocities required to accommodate the approximately 1000-fold difference between the width of the electron particle (matter) and the electron (Compton) wavelength (energy).

Since Li et al. (2009) reported that the burst-firing of a *single* neuron can modify the state of the entire cerebral manifold and Houweling and Brecht (2008) showed that a single neuron can determine the occurrence of an overt response the possibility that quantum-level energies can affect macroscopic processes has emerged as testable possibilities. In other words inordinately small energies, within the range discerned as functional quantum at the most fundamental levels of space-time, can initiate a cascade of events that result in a conspicuous change of the whole system, including overt behaviors. As a preparation for this potential transformation in the neurosciences, the thresholds for transitions between imaginary and real in Minkowski space-time were calculated for the four major spatial parameters: (1) the neuronal plasma membrane, (2) the soma width, (3) cerebral length, and, (4) the (length of) layer of charge that defines the membrane potential. Calculations were completed at 3 decimal places but were rounded to two. All of the values are not assumed to be exact but are expected to display distributions or dispersions around a central tendency.

2. The plasma cell membrane

The plasma cell membrane ($\sim 10^{-8}$ m) is considered the boundary condition that defines and maintains the existence of biological life through the polarity established by the maintained (temporally consistent) spatial disparity of charge. The addition of the three squared values (10^{-16} m^2) of the traditional three spatial dimensions (3×10^{-16} m^2), when subtracted from c^2 requires a minimum 0.33×10^{-32} s^2 in order for $\sqrt{} > 0$. In fundamental units this is 0.58×10^{-16} s which is within the time required for one orbit of an electron ($\sim 1.52 \times 10^{-16}$ s) in a classic Bohr magneton. Considering the range in coefficients for the empirical widths of plasma cell membranes, the solution may potentially converge with this orbital period. From one perspective access to 4D space from the plasma cell membrane would occur within the temporal increment associated with the single rotation of an electron.

This congruence is important because it relates two phenomena relevant to neurofunction and to neuroquantology. The first is the temporal similarity of the orbit time of a single (first order) electron and the time that would be required for a photon ($\sim 10^{8}$ m s^{-1}) to traverse a neuronal plasma cell membrane (10^{-8} m); it is in the same order of magnitude, 10^{-16} s. The juxtaposition of discrete durations for one unit orbit of an electron and the passage of a photon through a membrane allows the possibility of exchange of quanta of energy, and, in patterns of 0,1, information between light (photon packets) and membrane function. In a broader sense, the condition is set to allow a bidirectional process whereby the cell membrane receives information from light generated anywhere and anytime (Persinger, 2012a,b) and for photon emissions from cell membranes (Bokkon et al., 2010; Dotta et al., 2011a,b; Dotta

and Persinger, 2012; Isojima et al., 1995; Popp et al., 1988) to be emitted to any coordinate in space-time (Hu and Wu, 2006).

The second important correlate of 10^{-16} s is the convergence with the value for *h*, Planck's constant, or 6.62×10^{-34} J s. It is the quantitative foundation for the basis of quantum theory, that is, electromagnetic energy is confined to indivisible photons each of which has energy *hf* where *h* is Planck's constant and f is the frequency. The energy of an electron can be conceived as the product of its mass and the square of its (fine structure) velocity or 9.1×10^{-31} kg $(2.19 \times 10^{6}\ \mathrm{m\,s^{-1}})^2$ or 43.6×10^{-19} J. This value for one orbit ($2\pi f$) requiring 1.52×10^{-16} s would be 6.62×10^{-34} J s, that is, Planck's constant. The congruence between the discrete time for one orbit and the resulting value that defines Planck's constant suggests that a *singular* rotation could be considered a unit upon which potential 0,1 information might be associated.

3. The cell width

The second length relevant to human brain function is the average width of a cell body. Although cell soma in mammals can range from a diameter of ~6 μm to the width of a human ovum (~100 μm), the mean value is revealing. The parameters that determine the average width of a cell soma, about 10 μm, is the length obtained from average biological temperature (37 °C, 310 K) of homeotherms as well as the classical derivation of energy gaps. In the former case Wein's law, 0.29 cm K/K, predicts the median width of the standing wavelength would be 9.4 μm.

The frequency of this wavelength at c, the velocity of light, is 3×10^{13} Hz with an equivalent energy (multiplied by 6.62×10^{-34} J s) of 2×10^{-20} J. This is also the same increment of energy associated with a typical action potential of a neuron (Δv = 120 mV, 1.21×10^{-1} V) on a unit charge 1.60×10^{-19} As and is the energy between the approximately 10 nm distance between the potassium ions that generate the resting membrane potential. Stated alternatively, the frequency associated with this energy is $\sim 2 \times 10^{-20}$ J/6.62×10^{-34} J s, or 0.3×10^{14} Hz. At the velocity c this would be equivalent to a wavelength of 10 μm.

Similarly, the solution for gap energy is $E = hc/\lambda$, where *h* is Planck's constant and *c* is the velocity of light. For a unit energy of 10^{-20} J the solution is λ = 10 μm. The inclusion of *h* in this equation, considering it is the energy equivalence of the mass of an electron distributed within only one orbit (in conjunction with the 10^{-20} J), relates this neuroquantal energy to one form of quantum unit for the electron.

When the value of 10 μm is placed within a Minkowskian context, the value required to produce $\sqrt{} > 0$ in c^2t^2 is 0.33×10^{-26} s^2 or 0.58×10^{-13} s. This is equivalent to a frequency of 1.73×10^{13} Hz. The energy, obtained by its multiplication with 6.62×10^{-34} J s, is about 1.2×10^{-20} J. Hence within a Minkowskian-type hyperspace the value required to achieve the threshold between imaginary and real solutions is the same value associated with the energy coupled to the resting membrane potential and action potential of the neuron. Effectively, the threshold for transforming the virtual world into the world of matter in Minkowskian 4D space at the level of the cell is 10^{-20} J. In other words, the unit of energy associated with the most fundamental components of cognition and consciousness is also the quantity required for the transition from potential to kinetic matter.

Although at the macrolevel this energy might be considered extremely small, it is the quantity associated with all of the major intricate processes relevant to brain function (Persinger, 2010). The $\sim 10^{-20}$ J increment is the energy associated with the action potential, the energy between the potassium ions that are associated with the resting membrane potential, and the release of a single presynaptic vesicle. This neuroquantum occurs as the energy derived from the product of the voltage and current dipole of dendrites divided by the velocity of electrons, the limit of the number of enzymatic reactions per cell, and the energy involved with cell–cell adhesion through covalent bonds (Persinger, 2010).

Both phosphorylation and dephosphorlyation of enzymes, second shell hydrogen bond energy per molecule, and the energy associated with receptors sequestering ligands involve this increment as a fundamental unit. The energy required to stack one nucleotide on a RNA sequence is $\sim 10^{-20}$ J; the time required is ~1 ms. The consequence of the presence or absence in serial time of this quantum would therefore have the potential to affect the sequence of amino acids within proteins. The specificity of their composition determines the functions of neurons as well as their dynamic (enzymatic) properties. For example within the GluR1 subunit of the alpha-amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid receptor serine 831 is phosphorylated after long term potentiation while serine 845 is dephosphorylated after long term depression (Whitlock et al., 2006).

This neuroquantum of energy is released as low intensity photons from cells during periods of disequilibrium such as removal from incubation (Dotta et al., 2011a). When human volunteers are told to imagine white light within a completely dark setting, the net increase in photon emission is about 10^{-11} W m^{-2} relative to periods when they think only about mundane events (Dotta et al., 2012). When the cross sectional area of the side of the cerebrum is accommodated this is equivalent to 10^{-12} J s^{-1}. Assuming each action potential is 10^{-20} J, this would be equivalent to about 10 million neurons discharging at rates of about 10 Hz. The numbers of neurons are within the order of magnitude estimated from the volume of tissue that is activated during comparable cognitive tasks as measured directly by functional Magnetic Resonance Imaging (fMRI). That the processes of "thinking" might involve energies present at quantum levels was suggested by Bohr (1958) decades ago.

This Minkowskian solution of 10^{-20} J for the transition from "hyperspace" or "virtual" particles to real phenomena may be more important than imagined. The increment of 10^{-20} J as mediated by action potentials can be considered the major correlate or cause of "thought", cognition, and consciousness. One of the dualities of space involves the classical width of an electron ($\sim 2.82 \times 10^{-15}$ m) as a particle and the width derived from its energy, the Compton wavelength, which is 2.42×10^{-12} m. To obtain this degree of difference in contraction of length, according to Lorentz's classic formula, the velocity must reach ~0.9999995*c*.

The difference between the energy equivalence of an electron at *c* and this value is $\sim 2 \times 10^{-20}$ J (Persinger et al., 2008). This value is consistent in principle with Penrose's (1989) contention that consciousness, manifested as a quantum computation, involves collapse of a quantum field from a wave to particulate expression within brain space. In other words, the increment of change in energy that might define the electron as a particle or a wave is within the same order of magnitude as the bases of information within cerebral space, the action potential. It can be considered as the conservation of energy from the energy between the adjacent potassium ions that generate and maintain the resting plasma membrane potential.

4. The cerebral length

The longest brain-relevant space is the averaged length associated with the total volume (~1350 cm^3) of the adult brain, the cube root of which is between 11 cm and 12 cm. Assuming an averaged symmetrical length of 12 cm (0.12 m), the three dimensional metric is 3.6×10^{-2} m^2 and the value that must be multiplied by c^2 to allow $\sqrt{} > 0$ is 0.40×10^{-18} s^2 or 0.63×10^{-9} s. This is equivalent to

a frequency of 1.57×10^9 Hz (GHz) which is within error measurement of the 1.42 GHz (21 cm) hydrogen emission line or precession frequency. If the range of dispersion of samples of lengths of human cerebrums is accommodated the two values could converge. Statistically, there should be a subpopulation of human cerebrums that precisely converge on this value.

That the average length of the cube root of the volume of an adult human brain solves for the frequency associated with the most common element in the universe (when the transition value between imaginary and real numbers is considered) has significant implication. First, by virtual of the pervasive distribution of hydrogen throughout the universe, the precession frequency might be considered a cohesive temporal pattern that is a property of the universe as suggested by Ernst Mach's principle of imminence of the universe. Access to information within this frequency field would be more probable for those cerebral lengths that are most proximal to the precise value.

Although there is a range of solutions and a conservative approach is prudent when very large powers of ten are employed in a simplistic manner, "continuity" for the known universe could exist. The product of the estimated mass ($\sim 10^{52}$ kg) of the universe (Persinger, 2009), its width ($\sim 10^{26}$ m) and the Zitterbewegung or boundary for the zero point fluctuations ($\sim 10^{86}$ s^{-2}) is $\sim 10^{164}$ N. Assuming a Planck's voxel to be the cube of its length ($\sim 10^{-35}$ m) and a hence $\sim 10^{183}$ voxels in the universal (cubic) volume, the result is $\sim 10^{-19}$ N/voxel. When distributed over the hydrogen wavelength (distance) the energy is $\sim 10^{-20}$ J. Accommodation of coefficients, models for curvature of space, and related critical parameters expand the energies to within the visible spectrum (10^{-19} J).

Second, the quantum of energy associated with 1.42×10^9 Hz, when multiplied by 6.62×10^{-34} J s is 9.4×10^{-25} J. This is equivalent to the effect of a change of voltage of 0.6×10^{-5} V and is the quantity between the interface of the magnitude associated with a single ion channel (~ 0.3 μV) and the typical net change in membrane voltages associated with long term potentiation (LTP) in the hippocampal formation (Paradiso et al., 2007). LTP are remarkably robust phenomena that are considered the primary correlate of the representation of stimuli (experience), that is, memory (Nikonenko et al., 2002; Pan and Gan, 2008; Whitlock et al., 2006).

For most "LTP" effects the actual net "permanent" shift in hypopolarization from the baseline of membrane potentials, once the asymptote has been achieved, is about 1×10^{-5} V. LTP-related memory is particularly developed in the hippocampal formation and cerebral cortices where the microstructures, reflected as dendritic spines and synapses, are most obviously differentiated. Although this confluence does not prove that information associated with hydrogen precession can be reflected in memory processes, the similar levels of energy indicate a potential connection. However it is consistent with the supposition that the behavior of any part of the universe is determined by all of its part (Singh, 1961).

The Casimir solution (Bordag et al., 2001) when applied to the defining spatial parameters of brain space yields a range of values consistent with a universal interrelationship. The Casimir (finite) force between two parallel "neutral" plates = $(\pi^2/240)((\hbar c)/a^4)S$(area), assuming S is much larger than a (the separation between two surfaces); $\hbar$ is the reduced Planck's constant and c is the velocity of light. If the separation between the pre- and post-synaptic membranes (or even the width of the plasma membrane) is "a" and they are neutral for some Δt, the force in the area (1 μm^2) of a synapse is in the order of 1.3×10^{-7} N and when applied across the width of a membrane or synaptic cleft results in an energy of $\sim 10^{-15}$ J. The resulting frequency (f), obtained by dividing this value by Planck's constant is, assuming c, within the measurement error of the radius (c/f) of the hydrogen atom. The determining variable for precision would be contained within the exact value for the area of the synapse.

5. The layer of charge length

Considering the significance of the required frequencies for transitions between imaginary and real solutions of Minkowski space for the lengths of the membrane, cell, and human cerebrum, one test of the biophysical consistency of this approach would be the time required to yield $\sqrt{} > 0$ for the length of space involved with the generation of the membrane potential. Assuming a resting membrane potential of −70 mV (70×10^{-3} V) and the typical membrane capacitance of 10^{-6} F cm^{-2}, the value would be 7×10^{-8} As cm^{-2}. When applied to the surface area of a 10 μm diameter soma which is $\pi \times 10^{-6}$ cm^2, the number of charges responsible for the membrane potential of that cell would be $\sim 2.2 \times 10^6$.

Empirical measurements indicate that the K^+ concentrations associated with the resting membrane potential are about 130 μM cm^{-3} or 1.3×10^{-4} M cm^{-3}. Because the number of charges in a Mole (Faraday's constant) is 9.6×10^4 (As) M^{-1}, there would be 12.5 (As) cm^{-3}. The thickness of the layer would be 7×10^{-8} (As) cm^{-2} divided by 1.25×10^1 (As) cm^{-3} or 5.6×10^{-9} cm or 5.6×10^{-11} m. This length is effectively the radius of the Bohr magneton (5.4×10^{-11} m).

The insertion of the radius of the Bohr magneton into the Minkowski relation, requires a temporal value of 9.33×10^{-38} s^2 or 3.05×10^{-19} s for $\sqrt{} > 0$. The resulting frequency (0.33×10^{19} Hz) multiplied by Planck's constant results in an energy quantum of 2.169×10^{-15} J. This is a particularly important solution. It is one-half (.50) of Planck's constant expressed as eV (electron volts) s, or, 4.21×10^{-15} eV s. In the terms of quantum mechanics the spin of a particle corresponds to the product of its angular momentum (kg m^2, moment of momentum) and the moment of inertia (v/r). For the Bohr magneton this value is Planck's constant, h. All fundamental particles display a spin which is an integer or 1/2 of this constant. In the present model of the universe the particles that compose matter exhibit a spin of $1/2h$.

This suggests that the Minkowski solution for the radius of the Bohr magneton, which is a functional width of layer of charge that maintains the membrane potential, results in a value of energy that defines the primary matter from which we assume the brain is constructed. Consequently the temporal value required for virtual phenomena to be transformed to real phenomena within the effective space occupied by charges to maintain the resting membrane potential is a quantity that is the bases for the relationship between energy and the particles that mediate information through space-time (Persinger and Koren, 2007).

6. Conclusions

Mathematical formulations of non-Euclidean space have been considered abstracts with minimal correspondence to the locality that constrains brain phenomena. Nunez (1995) splendid treatise "Towards a physics of neocortex" demonstrated the utility of combining classical theory, mathematical relationships, and quantitative measurements to reveal the intrinsic relationship between brain function and the basic physics by which we describe the universe. The results of the present quantitative exploration of the classic formula employed to describe "hyperspace" or the 4D world indicates that the spatial increments defining the dynamics of human brain function are intimately connected with values that describe universal parameters, including the precession frequency of neutral hydrogen and the spin states that define matter.

Although the square root of a negative number has been considered "imaginary" (i) from a mathematical perspective, the physical and functional similarities of this quality with "virtual particles" may be more than metaphor. "Virtual particles" are presumed to exist as correlates of zero point fluctuations at the smallest increments of space. At specific "transition states", dependent in large part upon a changing boundary condition reflected in derivatives or rates of change rather than static conditions, they can transform into real particles. If the limens for "real" solutions to occur in hyperspace for the four primary increments of brain space are valid, then the optimal combination of those "threshold" values suggests that access to quantum phenomena, entanglement, non-locality, and the transformation of imaginary to real particles resides within the optimal manipulation of brain space and function.

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